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Case study

In vivo friction study of human skin: Influence of moisturizers on different anatomical sites

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Abstract

In order to understand the human haptic system, the mechanical characterization of skin contact is an important task. As the skin constitutes itself a surface, it is convenient to describe the problem using a contacting surface analysis, especially concerning the friction which occurs when the skin interacts with other surfaces. Several published works have shown that the analysis of the friction response of the skin can provide an indirect way to assess the skin condition.

The present study uses a new approach to evaluate in vivo the human friction measured by direct sliding action with an increase of the normal load. Two moisturizer ointments, petrolatum and glycerin, were applied in two anatomical sites of the individual submitted to this study. In order to evaluate hydration effects, this study also incorporates a direct characterization of the moisture content measuring the transepidermal water loss (TEWL).

The effect of the moisturizers as a function of time after the application was studied for different anatomical sites. The normal compression and the tangential forces were measured using a three-dimensional force sensor while slipping the skin over a spherical glass surface. The skin hydration was concomitantly monitored by measuring the TEWL.

Keywords: Friction human skin; Moisturizer; Skin conditioners

1. Introduction

Our skin is the largest organ of the body—a complex and dynamic system that is vitally important to our health. The skin is also the outermost part of our sensitive system, and when in interaction with the surrounding objects, skin acts both as a force transmitter and a sensor. The friction between the skin and the solid surfaces reflects this double role, limiting the tangential force transfer and reporting about the counter-surface texture, through pleasant and unpleasant feelings. The investigation of friction behaviour of the skin plays therefore an important role in both technical and health points of view [1].

The outer layer of skin is made up of dead skin cells, natural oils and lipids, to protect the deeper layers of skin from irritants and toxins. Contact with many substances, including some soaps and cleansers ingredients, strips away these protective elements of the skin surface. Once these irritants penetrate the outer layer of skin they can cause dry skin conditions and skin health problems. One of the most important functions of the skin is to provide a permeability barrier against excessive transepidermal water loss (TEWL). The constant water movement across skin (TEWL) plays an important role in signalling epidermal repair processes because it has been demonstrated that the barrier recovery is inhibited by occlusion [2]. TEWL is a very important non-invasive tool that is being used in both dermatology and cosmetology to monitor in vivo the skin barrier recovery after the application of skin products. In intact skin, the TEWL is very low but that value increases when the barrier is damaged. The recovery of the barrier can be traced by the decrease in the values of TEWL until normal values are reached [3,4].

Moisturizers are a very important part of dermatology since keeping the skin moist is one of the key factors in healthy skin. Most moisturizers available are composed of some formulation

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of oil and water, with added ingredients that may, or may not, help prevent specific skin problems. Petrolatum and glycerin are both moisturizers with different mechanisms of action. Petrolatum is occlusive because it creates a hydrophobic barrier over the skin that reduces TEWL values. Glycerin is a humectant and has the ability to attract water into the epidermis from both dermis and the atmosphere in case of high relative humidity. The humectants like glycerin can increase the TEWL because they promote the water absorption from dermis to epidermis and than to the environment.

Several studies were done recently to investigate the friction of human skin, some of them resorting to in vivo experiments. A review of experimental studies was published by Sivamani et al. [5] in 2003. In these studies, the experiments are usually conducted by applying a constant normal load during the test. The review pointed out a significantly scatter on the measured friction values: the values of the dynamic friction coefficient measured in vivo ranged from less than 0.2 to higher than 0.7.

Several studies describe attempts to use the tribological response of human skin to qualify some aspects of the skin behaviour [6]. The effect of the humidity was especially investigated; the response of drier and moistened skin was the essential goal of several friction studies [1,7–10]. Gender, age and anatomical sites have been also investigated by tribological tests [11–14]. The increase in friction with the addition of moisturizer creams was generally observed, and a significant change of friction with the anatomical site was observed by several researchers. The present work aims to study the friction of the skin, particularly the effect of anatomical site and the moisturizers substances petrolatum and glycerin. The research was done applying a new technique and the transepidermal water loss was also measured.

2. Experimental work

2.1. Friction equipment

Friction tests were carried out using equipment that was especially developed to measure the friction force which occurs during the sliding of the skin acting directly onto a glass surface. The tests consist of sliding the skin surface under study on a glass and simultaneously increasing the normal pressure (Fig. 1). As the sliding results from a direct action of the individual onto a glass surface, the test conditions are not exactly the same for all tests; however, the average conditions consist of a sliding distance of 50 mm, and a normal load ranging from 0 to 50–70 N. Typically, the loading rate and the sliding speed were respectively of 60 ± 20 N/s and 40 ± 10 mm/s. The equipment includes a multiaxial load cell and amplifier unit that allows the simultaneous measurement of the normal and tangential forces. Both forces are acquired to a computer as the test proceeds. The roughness Ra of the glass is 0.03 μm. In order to avoid edge effects, the glass has a gentle spherical surface with a radius of 85 mm.

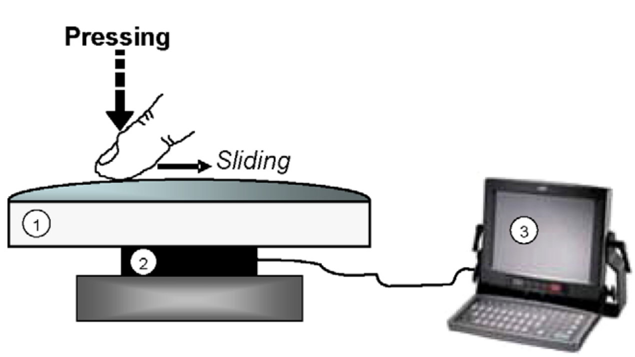

Fig. 1. Schematic view of the experimental test equipment. (1) Spherical glass surface. (2) Multiaxial force sensor. (3) Treatment and acquisition unit.

2.2. Skin preparation

The individual under study was a 45 years old Caucasian male. Two different anatomical regions were considered: the palm of the hand and the ventral face of forearm.

Five different pre-treatments were considered in the present study:

1. skin in natural and undamaged state: skin not washed for at least one hour prior to the test;
2. skin after washing: skin after washing with liquid soap and dried at room's temperature;
3. ethylic alcohol rinsing: skin was rinsed with ethylic alcohol and dried at room's temperature;
4. application of petrolatum: a thick layer of a general moisturizer substance, petrolatum, was applied to the skin. Before the test, and five minutes after application, the skin surface was cleaned with a facial paper tissue;
5. application of glycerin: a thick layer of a general moisturizer substance, glycerin, was applied to the skin. Before the test, and five minutes after the application, the skin surface was cleaned with a facial paper tissue.

Besides the pre-treatment and the anatomical region this study also considered the effect of the time after the treatment. Friction was monitored 5, 15, 30, 45 and 60 min after the application of the moisturizer substance.

For each test condition, five replicates were conducted in similar conditions. The results of each test were analysed separately in order to calculate the friction coefficient; afterwards, average and standard deviations values were calculated.

Before each test the glass surface was freshly cleaned with ethylic alcohol and dried with a paper tissue.

2.3. Processing of the results

Fig. 2 displays the typical evolution of both the normal and tangential forces during a complete test involving the loading and unloading phases.

According to the Amontons–Coulomb linear friction model, the friction force is proportional to the normal applied force, and the coefficient of proportionality corresponds to the friction coefficient. Therefore, if we assume this linear model and take into account the results available from each test, the best way to calculate the friction coefficient is to represent graphically the

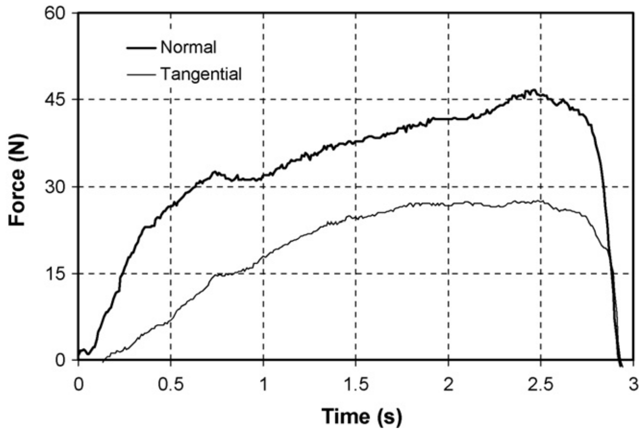

Fig. 2. Evolution of normal and friction forces with the passing of time.

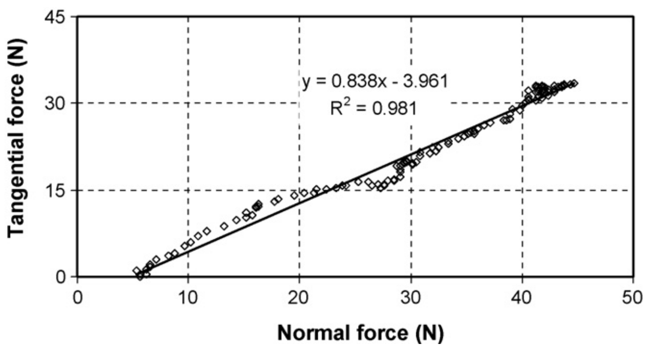

Fig. 3. Plot of the friction force against the normal load (linear, one stage). The resulting friction coefficient is the slope of the fitted linear line.

friction force as a function of the normal force. The slope of the linear relationship, fitted to the experimental data points, corresponds to the friction coefficient. In the present study, the friction coefficient was calculated considering only the experimental data points corresponding to the loading phase (Fig. 3).

For each condition five tests were conducted. The average and the standard deviation are considered for each skin condition.

2.4. Transepidermal water loss (TEWL)

Additionally, the transepidermal water loss was also measured, considering the same anatomical regions, moisturizer substances and the same delay. The TEWL is a measure of the insensible water diffusion through the skin, usually expressed in $g\,m^{-2}\,h^{-1}$. TEWL was measured using a Delfin–Vapometer wireless equipment, and the measurements were done according to the relevant guidelines [3].

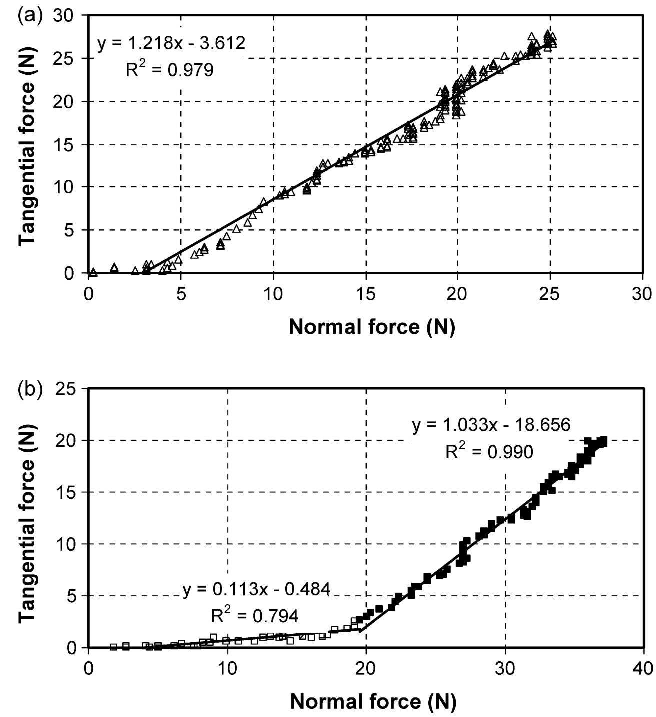

Fig. 4. Plot of the friction force against the normal load. (a) Hand, typical evolution in the natural state. The results agree with a single stage Amontons–Coulomb linear model. The friction coefficient is the slope of the fitted linear line. (b) Ventral face of the forearm, typical evolution in the natural state. The results agree with a double stage Amontons–Coulomb linear model. For each stage, the friction coefficient is the slope of the corresponding fitted linear line.

3. Results and discussion

3.1. Anatomical regions

The typical evolution of the friction force plotted against the normal force is characteristic of the anatomical region under study (Fig. 4).

For the tests carried out on the palm hand surface, all the results agree reasonably with a linear evolution according to the Amontons–Coulomb model (Fig. 4(a)). However, the tests conducted on the ventral forearm surface display a clear double slope. For the lowest values of the normal load, low friction occurs. Increasing the normal pressure, a transition to high friction occurs. One straight line can be therefore ascribed to each of the stages (Fig. 4(b)).

We note that Fig. 4 displays the friction results for the skin in natural state. The skin of the forearm shows a transition between the low friction and the higher friction regimes. In the

Table 1
Influence of the pre-treatment of the skin on the friction coefficient against glass

<table>
<tr><th></th><th colspan="3">Forearm</th><th colspan="3">Hand</th></tr>
<tr><th></th><th>Standard</th><th>Washed</th><th>Alcohol</th><th>Standard</th><th>Washed</th><th>Alcohol</th></tr>
<tr><td>1st phase</td><td>0.15 (0.034)</td><td>0.17 (0.074)</td><td>0.10 (0.035)</td><td rowspan="2">1.32 (0.08)</td><td rowspan="2">0.90 (0.26)</td><td rowspan="2">1.24 (0.21)</td></tr>
<tr><td>2nd phase</td><td>1.07 (0.08)</td><td>0.87 (0.059)</td><td>0.84 (0.19)</td></tr>
<tr><td>Transition load (N)</td><td>25</td><td>20</td><td>15</td><td></td><td></td><td></td></tr>
</table>

natural state of the skin this transition occurs for more or less 20 N.

3.2. Pre-treatment

In spite of the different pre-treatment studied, the typical evolution of the friction force plotted against the normal force remains unchanged. The hand skin always displays a linear evolution (Fig. 4(a)). The forearm skin reveals in all tests a double linear evolution with transition from low friction to high friction regime (Fig. 4(b)). Although the typical evolution remains constant, the corresponding friction coefficient varies with the skin pre-treatment. Table 1 summarises the average results and the corresponding standard deviations.

3.3. Moisturizers

The effects of the petrolatum and the glycerin on the friction coefficient were studied for both hand and forearm skins. Besides the influence produced immediately after the application, the friction was studied during one hour after the application of the moisturizer substance.

The tests conducted with the forearm skin always display the typical behaviour previously presented, characterized by a transition between low to high friction depending on the contact pressure. The low friction regime does not change significantly for both moisturizers and during the time; in this regime an average friction coefficient of 0.14–0.16 was obtained for all the tests. However, the high friction regime changed notably as a function of both the moisturizer substance and the time after the application. Therefore, only the friction coefficient corresponding to the second regime will be used in order to compare the influence of the substances applied to the skin. The effect of petrolatum and glycerin is different according to the anatomical sites studied. Fig. 5(a) and (b), respectively display the friction coefficient for hand and forearm skin and for the two substances. Concerning the forearm, the friction coefficient corresponds only to the high friction regime.

The use of these moisturizers leads to a significant decrease in the friction coefficient, as measured 5 min after the application. In all cases, but especially in the forearm, friction coefficient increases with time. In both anatomical sites, petrolatum leads to higher friction than glycerin.

The anatomical sites studied reveal a noticeable difference of the friction when compared to the standard values. For the hand, the friction coefficient is always significantly lower than the standard value, even one hour after the application. However, for the forearm the friction becomes higher than the standard value 15 min after the application of petrolatum and 45 min after the application of glycerin.

3.4. TEWL results

Transepidermal water loss was measured in the palm skin and in the forearm ventral face in the natural state, as reference or standard value, and after the use of the moisturizers, periodically during one hour after the application. Standard values were very different when measured on each of the anatomical sites considered, as expected after the previous results obtained by Grubauer et al. [2]. In fact, the standard values obtained were 100 and 9 g m^{-2} h^{-1}, respectively for the hand and for the forearm. In what concerns the effect of the moisturizers, Fig. 6 summarizes the evolution of TEWL for 1 h after the application of the petrolatum and the glycerin. The TEWL values are displayed as a percentage of the standard result.

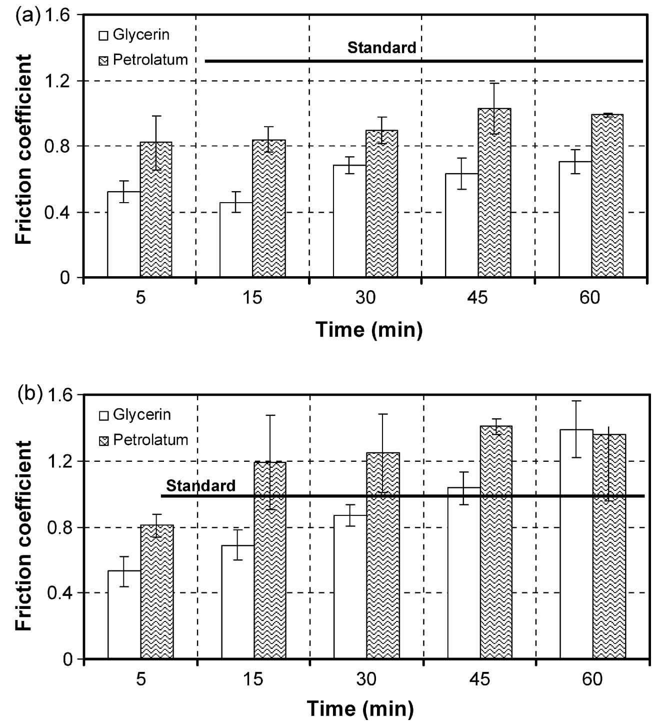

Fig. 5. Evolution of the friction coefficient with the passing of time after the application of petrolatum and glycerin. The horizontal line is the average friction coefficient for the natural state (standard condition). (a) Hand skin against glass. (b) Ventral face of the forearm against glass.

Regarding the influence of moisturizers, the effects of each substance were similar on both sites. The petrolatum leads to a slight increase in TEWL after application followed by a decrease, very small for the forearm and more significant for the hand. Concerning glycerin, the TEWL decreases after application, and remains lower than the standard for the period under analysis. As can also be observed in Fig. 6, glycerin leads to a higher variation than petrolatum. The possibility to correlate the friction results with the TEWL parameter was studied but no relationship could be established, which confirms the conclusions of Loden et al. [15].

3.5. Discussion

The present study reveals that not only the value of the friction coefficient but also the friction behaviour depend from the anatomical site. To the best of our knowledge this is a novel result: the published results conclude essentially that the skin friction coefficient varies with the anatomical site under test [11–14]. Previous work from the authors has shown that, for some individuals, the skin of fingertips may behave similarly to

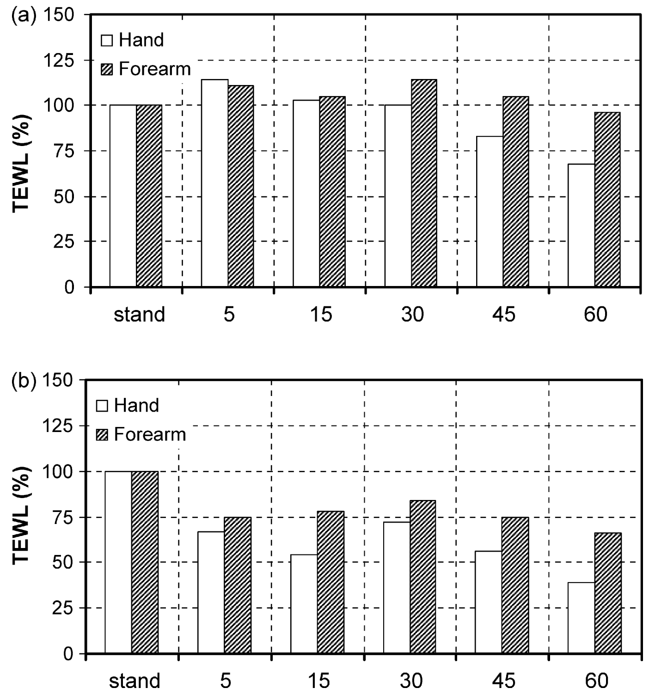

Fig. 6. Evolution of the transepidermal water loss (TEWL), versus time after application of (a) petrolatum and (b) glycerin.

the evolution now identified in the forearm, especially in women [16]. This change of behaviour from the hand to the forearm skin can be related to skin thickness. Thin skins seem to be more prone to present a double friction regime, comprising a low friction regime for lower loads and a transition to high friction above a specific normal load. The friction behaviour observed on the forearm may provide important insight in order to explain the significant scatter of the results published by different authors. These results may be situated both in the high and low friction regimes.

Concerning the effect of the moisturizers, it is expected that petrolatum would act by the formation of a top protective layer, reducing the water lost by evaporation, while glycerin is usually regarded as a humectant. Application of glycerin will thus smooth down the scales, and may lead to swelling of the stratum corneum. This mechanism is responsible for a surface-smoothing effect, obtained through long-term application that can be seen and felt after application of a moisturizer to the skin. Therefore, the fact that glycerin leads to a higher change in friction, results probably from its humectant effect. The difference observed in the effect of the moisturizers on the two anatomical sites can also be ascribed to the smoothing effect of the substances. In fact, the smoothing effect on the hand leads to a reduction on the surface patterns and thus to a reduction in the friction coefficient. However, in the forearm skin, results reveal a tendency to increase the friction coefficient above the standard value. This behaviour confirms other results mentioned in literature [11–14], and could be due to further smoothing of a skin which is already naturally smooth. This leads to an increase in the contact area and a rise in the friction coefficient. It should also be noted that glycerin is absorbed more promptly than petrolatum. This is one of the reasons why glycerin induces, in this case, a drop in TEWL, while the occlusive effect of petrolatum is possibly eliminated upon removal as the 5 min period of application ends. Another explanation for the difference in the behaviour of the anatomical sites could be the change of the skin elastic properties induced by the skin conditioners themselves or by the change in the TEWL which was clearly showed by Johnson et al. [10].

4. Concluding remarks

The contact of human skin and glass surface was studied in vivo. Two anatomical sites have been investigated: the palm of the hand and the forearm ventral face. The results reveal that the friction behaviour depends from the anatomical site. The skin of the hand displays a steady state regime, with a constant friction coefficient along the range of evolution of the normal load, while the forearm skin exhibits a friction characterised by two regimes. The first one, corresponding to low normal loads, is characterized by low friction coefficients. Above a critical normal load, a second regime occurs with higher friction. The pre-treatment of the skin changes significantly the friction coefficient, particularly the previous application of moisturizers. However, a dependence on the anatomical site was also found for this effect. After the application of petrolatum or glycerin, the friction of the palm of the hand suffers a reduction compared to the value measured in natural state, used as standard reference value. This effect remains for at least one hour after application. For the forearm skin, a decrease in the friction coefficient occurs immediately after the application of the substances; however, a tendency to an increase with time is observed. Thus, after 15 or 45 min of the application of respectively petrolatum and glycerin, the standard value is surpassed. Compared to petrolatum, glycerin induces a larger change in the friction values, compatible with a higher degree of absorption.

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